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EFFECTS OF IRRIGATION METHODS AND SYSTEM MANAGEMENT ON WATER APPLICATION EFFICIENCY*

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SUMMARY

Efficient use of water in irrigated agriculture is as important in areas of plentiful water supply as it is in water-short areas. Much of the water delivered to the farm for irrigation is lost while applying it to the land because of the system management practices followed.

Field-water application efficiency is the precentage of water delivered to a field that is stored in the soil within the root zone of the growing crop. Factors affecting field-water application efficiency in irrigation are climate, soil, crop, water supply, topography, method of irrigation, irrigation system design, and irrigation system operation.

Water is applied to the land by four general methods: flooding, furrows, sprinkler, and subirrigation. Each of these methods has charactersitic water losses, but all losses can be classified under evaporation, deep percolation, or runoff.

Water-application efficiency studies have been conducted at a number of locations in the United States. This paper summarizes a study conducted near Boise, Idaho to compare the field-water application efficiencies of the furrow, border, contour border, and sprinkler methods of irrigation of crops in a grain-legume rotation on 3 to 5 per cent slopes.

The contour border method of irrigation gave the highest water

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* Les effets de méthodes d'administration d'un système d'irrigation sur l'efficacité de l'application des eaux.

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application efficiency for the greater depth of soil moisture replacement each irrigation, whereas the sprinkler method gave the highest efficiency for shallow depths of soil moisture replacement.

The water application efficiency obtained in the Boise study was higher than those measured on farmer irrigated fields with similar soils, slopes, and crops. This was because more control equipment, more labor, and better land preparation were used in the detailed study.

Maximum water application efficiency requires good water control equipment, proper land preparation, correct irrigation system designs, and proper management of the irrigation system.

RESUME

L'emploi efficace des eaux dans les terrains irrigués est tout aussi important dans les régions où il y a une abondance d'eau que dans les endroits où il y a un manque d'eau. Une grande partie des eaux livrées à la ferme pour l'irrigation est perdue en l'appliquant à la terre à cause des procédés employés dans l'administration du système.

L'efficacité d'irrigation, c'est le pourcentage des eaux livrées à un terrain qui est accumulé dans le sol à l'intérieur de la zone des racines de la culture croissante. Les considérations qui touchent à l'efficacité de l'application des eaux, c'est-à-dire l'efficacité d'irrigation, sont le climat, le sol, la culture, la provision d'eau, la topographie, la méthode d'irrigation, le dessin du système d'irrigation et l'opération maniement du système d'irrigation.

On fait l'application des eaux au terrain au moyen de quatre méthodes générales: inondation, sillons, arrosage et irrigation souterraine. Chacune de ces méthodes a ses pertes d'eau caractéristiques, mais toutes ces pertes sont les résultats d'évaporation.

On a fait des recherches au sujet de l'efficacité de l'irrigation dans plusieurs endroits aux Etats-Unis. Ce mémoire est un résumé d'une étude faite près de Boise, Idaho, pour comparer, l'efficacité des méthodes d'irrigation au moyen du sillon, de la plate-bande, du plate-bande contouré et d'arrosage. On a pratiqué l'assolement grain-légume sur des pentes de 3 à 5 pourcent.

La méthode d'irrigation par plate-bande contouré a rendu la plus grande efficacité d'irrigation en tant que la plus grande profondeur du remplacement de la moiture du sol pour chaque application, tandis que l'arrosage a rendu la plus grande efficacité pour le remplacement de moiture du sol moins profond.

L'efficacité d'irrigation obtenue par l'expérience à Boise était plus grande que celles mésurées dans les fermes où les fermiers eux-mêmes irriguent leurs champs dont les sols, les pentes et les cultures sont pareils. Cette efficacité était le résultat de plus d'équipement de

contrôle, plus main-oeuvre et une meilleure préparation du tarrain utilisés dans l'étude détaillée.

Le maximum d'efficacité de l'application des eaux exige un bon équipement de contrôle, des dessins exacts du système d'irrigation, et l'administration convenable du système d'irrigation.

INTRODUCTION

When good water is plentiful and low in cost, it is taken for granted and very few people are concerned about its use. But with an increasing demand for specialized crop production in arid areas and for agricultural products in countries experiencing a food shortage, and with increasing industry to support an ever-growing population, water supplies will need to be stretched. There are two principal ways to increase the available supplies : (1) the reclamation of saline waters and (2) more efficient use of the water now available.

Efficient use of water in agriculture is as important in areas of plentiful water supply as it is in the water-short areas. Proper utilization of irrigation water on farms results in maximum returns from the fertilizers applied, a reduction in labor and water costs, and reduced areas of waterlogged lands and drainage problems. Since 46 per cent of all water used in the United States is used for irrigated agriculture(8), any improvement in irrigation efficiency will have the effect of stretching the available water supplies.

DEFINITION OF TERMS

The term "irrigation efficiency" is defined by Israelsen(5) as "the ratio of the water consumed by the crops of an irrigation farm or project to the water diverted from a river or other natural water source into the farm or project canal or canals."

Irrigation efficiency is a composite term covering many of the water losses in irrigation that can be defined separately if desired. Among these are water conveyance efficiency, farm water application efficiency, field water application efficiency and water distribution efficiency. These efficiency terms were defined to permit evaluation of the various components of an irrigation project. The prime objective of these definitions is the promotion of better utilization of our water supplies.

The water conveyance efficiency term was developed by Israelsen(5) to evaluate the loss in conveying water from the streams, reservoirs, or other sources to the farm. Farm water application efficiency was developed to determine the percentage of the water delivered to the farm headgate that is stored in the root zone of the soil for use by plants. Field water application efficiency is a term similar to the farm water application efficiency, except that the area considered is a field instead of a farm. Distribution efficiency is an index of the uniformity of water application over an irrigated field.

FACTORS AFFECTING EFFICIENCY

Factors affecting irrigation water application efficiency at any one site or field are climate, soil, crop, water supply, topography, method of irrigation, labor, irrigation system design, and irrigation system operation.

CLIMATE

The climate affects the losses by evaporation before the water enters the soil. Frost and Schwalen(4) after 700 sprinkler tests state that "Losses increase with temperature, wind movement, operating pressure and degree of breaking of spray, and decrease with increase in humidity, and nozzle diameter." Blaney and Muckel(1) state that "evaporation increases under conditions of low humidity. It increases with high temperatures and decreases with low temperatures. Wind increases evaporation from small water surfaces by replacing moist air over the water with drier air moving in from a distance."

Linsley, Kohler and Paulhus(7) sum up the climatic factors affecting evaporation in this manner: "It can be stated, however, that the rate of evaporation is influenced by solar radiation, air temperature, vapor pressure, wind, and possibly atmospheric pressure."

SOILS

Very few soils are uniform. Intake rates may be very slow for many fine textured soils but very fast for some sands. The available water storage capacity also varies from very high to very low for the same range of soils. Soils with slow intake rates and high water storage capacities require longer irrigation water applications. As a result, irrigation of these soils is subject to greater losses by evaporation for all methods of irrigation and by runoff at the ends of furrows and borders. High intake rate soils may result in large deep percolation losses unless the system is correctly designed. All these losses will reduce the field water application efficiency.

CROPS

Some irrigated crops have a shallow root zone; others have a deep root zone. The first case will require frequent, shallow irrigations, which are generally less efficient than less frequent, deep irrigations.

WATER SUPPLIES

The water supply may be more than adequate. Consequently, much water is wasted. The author has observed that in areas having a deficient water supply, irrigators are usually more efficient than in those areas having a surplus water supply.

TOPOGRAPHY

The topography has a definite effect on the efficiency of irrigation. Level or nearly level fields are easier to irrigate and usually more efficient water application results. Irregular topography is more difficult to surface irrigate and the potential water losses from deep percolation and runoff are greater because of uneven water distribution.

IRRIGATION METHOD

The method of irrigation affects the efficiency of water application. In obtaining a uniform irrigation with furrow and border irrigation methods, some deep percolation and some runoff losses often result. Sprinkler irrigation has evaporation losses together with deep percolation losses due to uneven water distribution pattern. Basin and contour border irrigation often do not have any runoff losses but may have losses from deep percolation.

LABOR

The labor supply and its cost have a very definite effect on the efficiency of irrigation. With adequate labor, the loss of runoff water from furrows and borders can be reduced by decreasing streams size as the soil intake rate decreases. Irrigation sets can be changed when necessary, thereby reducing deep percolation losses in all methods of irrigation.

IRRIGATION SYSTEM DESIGN

Without the proper irrigation system design, efficient water application is not possible. Too long runs in furrow, border, or contour border irrigation will result in deep percolation losses if an adequate irrigation is applied to all areas in the field. Runoff and deep percolation losses or a combination of these two losses can occur from improper design of sprinkler systems.

IRRIGATION SYSTEM OPERATION

Correct operation of an irrigation system in accordance with the climate, soil, and needs of the crop is necessary to obtain high water-application efficiency. The efficiency of most farm irrigation systems can be improved by applying water when the crop needs it, stop irrigating when the soil reservoir in the root zone of the crop has reached field capacity, and controlling runoff by using proper stream sizes for the surface methods of irrigation and proper nozzle sizes and pressures for the sprinkler method of irrigation. A correctly-designed irrigation system when properly operated will give the highest efficiency.

EFFICIENCY STUDIES

Numerous irrigation efficiency studies have been conducted at various locations in the United States. Some of the more recent studies have been conducted in Idaho, Nebraska(9) and Utah(8). Similar methods were used for collecting the data used to calculate the individual irrigation efficiency. The amount of water delivered to, and the runoff from the same area were measured for each irrigation. The amount of water stored in the soil during each irrigation was determined by soil sampling before and after the water was applied. The water application efficiency was the percentage of the water applied that was stored in the root zone of the soil.

At Boise, Idaho, a study was conducted to compare the efficiency of water-application of the sprinkler, downslope furrow, downslope border, and contour border methods of irrigation.

This study was conducted on lands in the Black Canyon Irrigation District, near Caldwell, Idaho. The dominant soil is the Chilcott series. Associated with it in a complex of small spots are the Sebree and Vickery series. The Chilcott soil series was formed from a thin layer of loess overlying unconsolidated or very poorly-consolidated fluviatile, fan, or lacustrine sediments of the Idaho, Payette, or other closely related formation of Pliocene, early Pleistocene, or older age. The soil has a silt loam surface with silty clay loam subsoil. Slopes vary from 3 to 5 per cent. There is a lime hardpan underlying the area at a 1·5 to 3·0 feet in depth.

This area, which had never been irrigated before, was cleared of sagebrush and native grasses and then prepared for cropping. Fields were laid out and sprinkler and downslope furrow irrigation systems were installed in 1949. In the spring of 1953 downslope and contour border systems were installed on fields formerly furrow irrigated.

The sprinkler system consisted of a pump, motor, 6-inch main pipeline and a lateral made up of 4-inch and 3-inch aluminium tubing. Sprinklers were spaced 40 feet apart on the lateral and the lateral was moved 60 feet on the main pipeline. The water applied to the field by sprinklers was measured by a water meter placed in the lateral sprinkler line.

Water was applied to the downslope furrow field through gated pipe. Furrows were spaced 2 feet apart. The gated pipe was connected to a turnout structure, which received water delivered through a concrete pipeline from the measuring structure.

The downslope border and contour border fields were also irrigated using gated pipe. Border ridges were spaced 14 feet apart for both methods. The contour borders had a slope in the direction fo flow of 0·1 foot per hundred feet.

The amount of water applied to the downslope furrow, downslope border, and contour border fields was measured, using 90° V notch weirs and water stage recorders at the head of each field. The runoff from each of these fields and from the sprinkled area was measured using the same type of measuring equipment.

The cropping pattern followed on these fields was the grain-legume rotation used by most farmers in the area. The same tillage and fertilizer practices were applied to all fields.

The amount of water (d) stored in the root zone of the crop was calculated from data obtained by soil sampling the irrigated areas before and after each irrigation. The soil-samples were taken in 1-foot increments to the Caliche hard pan layer underlying the fields. Samples were taken from 17 locations in the sprinkled field, 12 locations in the downslope border field, and 6 or more locations in the contour border and downslope furrow fields. Each soil sample was weighed, dried in an electric oven at 105°C., weighed again and the percentage of moisture (P_w) computed on a dry weight basis([2]). The following formula was used to calculate the depth of water in each soil sample :

$$d=\frac{P_w A_s D}{100} \qquad \ldots(1)$$

where d is the depth of water in the soil sample in inches, P_w is the percentage of moisture on a dry weight basis, A_s is the volume weight of the soil in grams per cubic centimetre, and D is the depth of the soil sample in inches.

The amount of water retained in the soil from an irrigation is determined by subtracting the amount stored in the soil before irrigation from that stored in the soil after irrigation. This amount was corrected for the crop consumptive use for the period between soil sampling dates.

The amount of water consumptively used between the before and after irrigation soil-sampling periods was determined by computing the daily rate of crop use for the before irrigation period and projecting this rate for the number of days between the soil samplings before and after the irrigation water was applied.

The amount of water retained in the soil from an irrigation was calculated by use of the following equation:

$$d_s=d_a-d_b+n\ (cu) \qquad \ldots(2)$$

where d_s is the amount of water retained from an irrigation in inches, d_a is the depth of water in the soil profile after irrigation, d_b is the depth of water in the soil profile before irrigation, n is the number of days between soil samplings, and cu is the daily consumptive use for the period preceding the application of irrigation water.

The field-water application efficiency was calculated by dividing the amount of water retained from an irrigation (ds) by the amount

TABLE I

Summary of irrigation and related data for four methods of water application in 1955

Irrigation number	Depth applied	Rainfall during irrigation	Total water on field	Soil moisture storage	Consumptive use between soil samplings	Total water available in soil	Application efficiency	Crop, consumptive use data, and yield
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Per cent*	
Downslope furrows								
1	12·6	0·3	12·9	3·5	1·7	5·2	40	Alfalfa mixed with hard fescue grass. Yearly consumptive use—28·3 inches. Yield—3·9 tons per acre.
2	10·9	0·1	11·0	2·3	1·1	3·4	31	
3	15·5	1·0	16·5	1·7	1·8	3·5	21	
4	15·8	0 0	15·8	4·3	0·8	5·1	32	
5	15·5	0·0	15·5	3·7	0·8	4·5	29	
6	13·6	0·0	13·6	0·9	0·8	1·7	13	
7	3 0	0·3	3·3	1·1	0·6	1·7	52	
Season Total	86·9	1·7	88·6	17·5	7·6	25·1	28	
Downslope borders								
1	8 6	0·3	8 9	2·4	1·0	3·4	38	Alfalfa mixed with hard fescue grass. Seasonal consumptive use—27·5 inches. Yield—3·8 tons per acre.
2	8·8	0·0	8·8	2·7	1·3	4·0	45	
3	9·9	0·0	9·9	2·1	1·3	3·4	34	
4	10·8	0·0	10 8	2·8	1·3	4·1	38	
5	7·4	0·0	7·4	2·8	0·9	3·7	50	
6	7·3	0·6	7·9	2·7	1·0	3·7	47	
7	2·1	0·3	2·4	1·1	0·8	1·9	79	
Season Total	54·9	1·2	56·1	16·6	7·6	24·2	44	

Contour borders								
1	7·7	0·3	8·0	2·6	1·	3·9	49	Alfalfa mixed with hard fescue grass. Yearly consumptive use—27·1 inches. Yield—3·4 tons per acre.
2	7·1	0·0	7·1	1·8	0·6	2·4	34	
3	6·5	0·0	6·5	3·4	0·6	4·0	62	
4	8·7	0·0	8·7	1·4	1·4	2·8	32	
5	6·3	0·0	6·3	3·4	0·5	3·9	62	
6	7·6	0·6	8·2	1·6	2·0	3·6	44	
7	4·5	0·3	4·8	1·0	0·4	1·4	29	
Season Total	48·4	1·2	49·6	15·2	6·8	22·0	44	
Sprinklers								
1	5·6	0·3	5·9	2·2	1·4	3·6	61	Alfalfa mixed with hard fescue grass. Yearly consumptive use—28·3 inches. Yield—3·8 tons per acre.
2	5·8	0·1	5·9	2·7	1·1	3·8	66	
3	3·7	0·2	3·9	1·2	1·8	3·0	77	
4	6·6	0·0	6·6	2·8	1·1	3·9	59	
5	7·3	0·0	7·3	2·2	1·8	4·0	55	
6	4·7	0·7	5·4	2·1	1·8	3·9	72	
7	4·0	0·3	4·3	0·7	0·9	1·6	37	
Season Total	37·7	1·6	39·3	13·9	9·9	23·8	61	

of water applied to the fields corrected for the rainfall that occurred between soil sampling periods.

The rainfall occurring between the before and after irrigation soil sampling dates was measured by a standard Weather Bureau rain gauge. The precipitation obtained was added to the irrigation depth.

Field application efficiency was calculated by the following equation:

$$E_{field} = \frac{d_s}{d_o + r} 100 \quad \ldots(3)$$

where E_{field} is the field-water application efficiency in percent, d_s is the amount of water retained in the root zone of the soil from an irrigation in inches, d_o is the depth of water applied to the field in inches, and r is the rainfall that occurred between soil sampling periods.

A summary of the data obtained for each method of water application for the 1955 irrigation season is shown in Table I. Also shown is the yearly consumptive use as measured from soil sampling on each field and the yield of the alfalfa mixed with hard fescue grass crop.

A summary of the data obtained for each method of water application for each irrigation season is shown in Table II, together with totals of water applied, water stored and overall water application efficiency. Seasonal consumptive use as calculated from soil sampling and crop yields for each crop is shown.

A summary of the data obtained for all irrigations shows that for the downslope furrow method, the mean soil moisture storage in the root zone depth and field-water application efficiency for 33 irrigations was 3·3 inches and 36 per cent, respectively. For the downslope border method, the mean water stored and field-water application efficiency for 24 irrigations was 3·4 inches and 43 per cent. The contour border method showed for 22 irrigations an average of 3·5 inches of water stored in the soil per irrigation with a field-water application efficiency of 62 per cent. Under the sprinkler method of irrigation for 41 irrigations with an average of 2·8 inches of water stored per irrigation, the field water application efficiency was 61 per cent.

The individual field-water application efficiencies were analyzed to obtain the variation in efficiency with depth of water retained in the soil profile. The regression equation and correlation coefficient were determined for each method of irrigation. Figure 1 shows the results of this analysis. Field water application efficiency increased with the greater amount of water stored in the soil for all methods of irrigation. The sprinkler method of irrigation gave the highest efficiency for shallow irrigations and the contour border method gave the highest efficiency for the heavier water applications.

Another study of field water application efficiencies for sprinkler and border made in Nebraska and reported by Somerhalder(9)

TABLE II

Summary of irrigation and related data by years for four methods of water application 1950-56

Year	Total water on field *Inches*	Total water available in soil *Inches*	Average application efficiency *Per cent*	Crop	Seasonal consumptive use *Inches*	Yield *Per acre*
			Downslope furrows			
1952	101·2	34·5	34	Red clover	23·0	hay 1·4 tons seed 167 lbs.
1953	13·1	5·3	40	Barley	10·9	60·4 bu.
1954	63·4	25·5	40	Alfalfa and hard fescue grass	25·4	1·9 tons
1955	88·6	25·1	28	Alfalfa and hard fescue grass	28·3	3·9 tons
1956	56·4	26·4	47	Alfalfa and hard fescue grass	25·0	4·8 tons
Total	322·7	116·8	36			
			Downslope borders			
1953	15·2	6·8	45	Barley	11·4	66·6 bu.
1954	48·7	21·9	45	Alfalfa and hard fescue grass	21·6	1·6 tons
1955	56·1	24·2	44	Alfalfa and hard fescue grass	27·5	3·8 tons
1956	69·4	28·1	40	Alfalfa and hard fescue grass	25·7	4·7 tons
Total	189·4	81·0	43			
			Contour borders			
1954	35·7	24·5	69	Alfalfa and hard fescue grass	25·5	1·1 tons
1955	49·6	22·0	44	Alfalfa and hard fescue grass	27·1	3·4 tons
1956	37·1	29·6	80	Alfalfa and hard fescue grass	27·2	4·3 tons
Total	122·4	76·1	62			

TABLE II—(*Continued*)

Year	Total water on field	Total water available in soil	Average application efficiency	Crop	Seasonal consumptive use	Yield
	Inches	*Inches*	*Per cent*		*Inches*	*Per acre*
			Sprinkler			
1950	9·8	7·5	76	Barley	—	28·1 bu.
1951	26·3	16·4	63	Red clover	—	No harvest
1952	21·6	13·9	64	Red clover	21·0	hay 1·2 tons seed 114 lbs.
1953	11·1	7·1	64	Barley	11·2	69·7 bu.
1954	33·5	19·9	59	Alfalfa and hard fescue grass	21·6	1·7 tons
1955	39·3	23·8	61	Alfalfa and hard fescue grass	28·3	3·8 tons
1956	43·9	24·5	56	Alfalfa and hard fescue grass	24·0	5·1 tons
Total	185·5	113·1	61			

showed efficiencies of 72 per cent under border irrigation and 84 per cent under sprinklers for the same conditions of soil, crop, and tillage practices.

The Nebraska study was conducted on a fine sandy loam soil with a 1 per cent slope. The Idaho study reported here was conducted on a silt loam surface soil having a clay loam subsoil with a 3 to 5 per cent surface slope. The basic intake rate for the Nebraska soil was reported to be 0·5 to 0·6 inch per hour, while the Idaho soil has a 0·12 to 0·13 inch per hour rate. "Basic intake rate" is the rate at which water will enter the soil after a period of several hours, when the change in rate becomes very slow([3]). The laboratory determinations of moisture capacities at one-third atmosphere tension (field capacity) and at 15 atmosphere (wilting point) were 18·2 and 9·5 per cent for the Nebraska soils. The Idaho soils showed 23 and 12 per cent. The equipment used to apply water in these comparisons of field water application efficiency was comparable. An examination of the reasons for a difference in water application efficiencies pointed to two factors—the slope and the basic intake rate of the soil.

Measurements of field water application efficiencies made by the author on farms adjoining the Boise, Idaho test area, showed that the farmers were obtaining field water application efficiencies of 19 to 33 per cent. In Utah([6]) the farmers were obtaining field water application efficiencies on 145 fields varying from 6 to 93 per cent with a mean efficiency of 41 per cent on furrow and border irrigated fields.

Much of the variation in field water application efficiency on the farm is due to poor water management. Those farmers

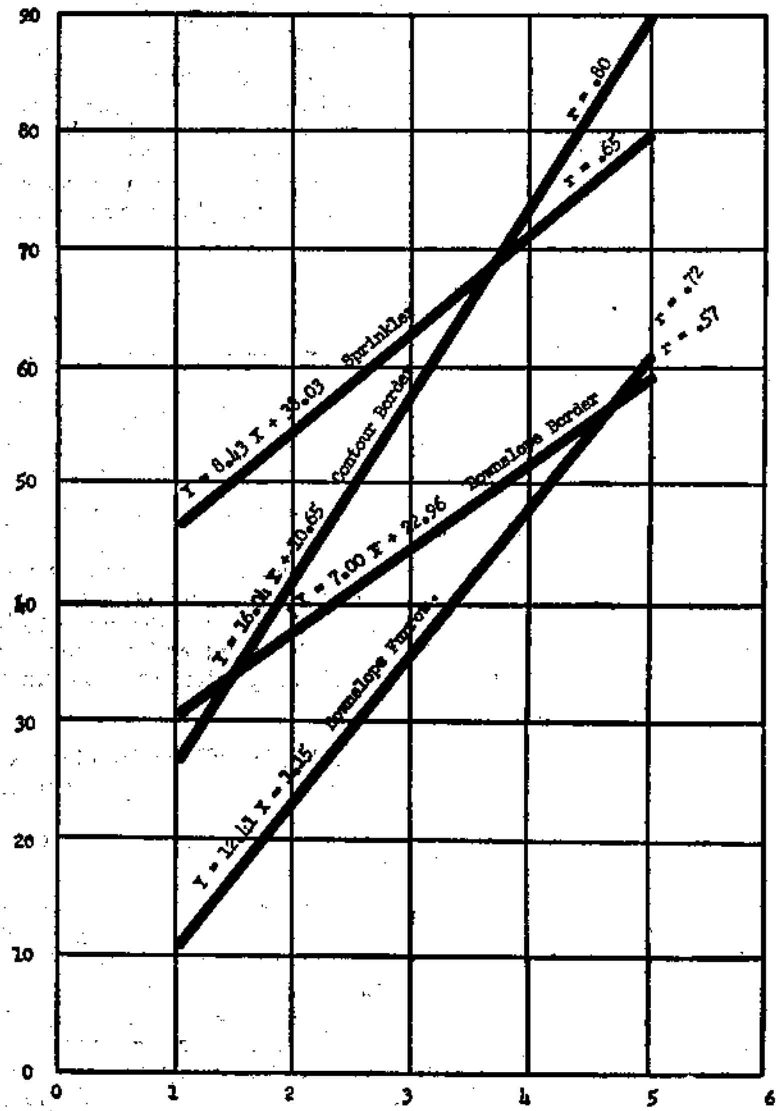

FIGURE 1 :—Variation of field water application efficiency with depth of water retained in the soil profile under the downslope furrow, downslope border, contour border and sprinkler methods of irrigation. Black Canyon Irrigation Investigations. Boise, Idaho, 1957.

obtaining the highest efficiencies applied water when the crop needed to be irrigated. They cut back furrow and border streams, thus reducing runoff. They used the water saved to irrigate more furrows and borders. The most efficient farm irrigator checked the depth of water penetration with a soil auger, probe, or shovel at various parts of the field to determine when an adequate, uniform irrigation had been obtained. If deep percolation losses were discovered at the top of the field the farmer increased the furrow or border stream on the next irrigation to reduce the time for getting the water through the furrow or border. This reduced deep percolation at the upper end of the field by making the time for water intake on each part of the furrow or border, more nearly the same. More attention to water management was obvious where the most efficient field water application efficiencies were being obtained.

CONLUSIONS

A study of field water application efficiency on a shallow soil having a surface slope of 3 to 5 per cent showed an efficiency of 36 per cent for 35 irrigations by downslope furrows, 43 per cent for 24 irrigations by downslope borders, 62 per cent for 22 irrigations by contour borders, and 61 per cent for 41 irrigations by sprinklers.

A study of the field water application efficiencies in relation to the depth of water replaced in the soil in the crop root zone showed lower efficiencies for small amounts of soil moisture replacements and higher efficiencies for the larger soil moisture replacements regardless of the method of irrigation. The sprinkler method was the most efficient method for a 1-inch soil moisture replacement and the contour border was most efficient for a 4-inch or greater soil moisture replacement.

A comparison of the furrow and border efficiencies obtained in the Idaho study and in a Nebraska study showed that for border and sprinkler methods of irrigation the more favorable irrigation conditions of high intake rate, deep soil, and level topography gave higher field water application efficiencies.

The Idaho field water application efficiency studies gave much more efficient water application than was measured on farmer-irrigated similar soils and slopes. The explanation for this is that more water control equipment, more labor, better land preparation for irrigation and better water management practices were used by research workers. When the cost or scracity of water makes it more economical for the farmer to invest in good water control equipment, proper land preparation, proper irrigation system design and adequate labor, then by using proper water management practices the water application efficiency will increase. Ultimately the time may come when only two methods of irrigation will be used. These will be some forms of basin and sprinkler irrigation, because it is possible to get more efficient water application with these methods as shown in the Idaho, Nebraska and other studies.

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